

Final Progress Report

Experiments and Spectral Studies of Martian Volcanic Rocks: Implications for the Origin of Pathfinder Rocks and Soils

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Project Summary

Research on this project was spread over several tasks during the past year. A paper on the effects of SNC basalt crystal content and degree of late-stage oxidation on the spectral properties of the rock was completed and has just appeared in JGR-green (Minitti et al., 2002). This task was an investigation of the possible effects of oxidation on the VISNIR and mid-infrared spectral properties of a pyroxene- and plagioclase-bearing basalt with Hi-FeO and low-Al as is characteristic of SNC parental melts. The goal was to determine whether oxidation effects which produced an obvious reddening of the spectra, could affect the pyroxene/plagioclase ratio estimated from the mid-IR spectra (Minitti et al., 2000; 2001b). In addition, synthesis and oxidation of two SNC-related andesite composition melts at different crystal contents has been completed. The two compositions contain 62 and 57 wt % SiO₂ respectively, and can be produced from a SNC parental melt such as A* (Minitti and Rutherford, 1999) after 40 and 30 % crystallization, providing there is 1-1.5 wt % dissolved water in the parental SNC basalt. Work to crystallize, variably oxidize and characterize the spectral properties of these compositions is now essentially complete, and a paper is in the early stages of writing. Work is also now in progress on the task to create SNC-type basalts with a wide range of pyroxene to plagioclase ratios by adding plagioclase to a synthesized SNC basalt such as A*. The spectral characteristics of these samples should help to determine why the spectra of the Mars surface do not appear to contain a signature from an early Al-rich Mars crust.

Summary of Research recently completed and in progress

The composition and spectral properties of the Mars Pathfinder rocks and soils together with the identification of basaltic and andesitic Mars terrains based on Thermal Emission Spectrometer (TES) data raised interesting questions regarding the nature and origin of Mars surface rocks. We have investigated the following questions (1) are the Pathfinder rocks igneous and is it possible these rocks could have formed by known igneous processes, such as equilibrium or fractional crystallization, operating within SNC magmas known to exist on Mars? If it is possible, what P (depth) and P_{H_2O} conditions are required? (2) whether TES-based interpretations of plagioclase-rich basalt and andesitic terrains in the south and north regions of Mars respectively are unique. Are the surface compositions of these regions plagioclase-rich, possibly indicating the presence of old Al-rich crust of Mars, or are the spectra being affected by something like surface weathering processes that might determine the spectral pyroxene to plagioclase ratio?

Task (1): Origin of Pathfinder sulfur-free rock composition

Minitti and Rutherford (1999; 2000) completed a set of experiments that appear to answer the question “Is there a petrogenetic link between Pathfinder rocks and soils and SNC magmas, and if so, what processes are involved?” The melt that was in equilibrium with olivine + Ca-pyroxene in the Chassigny magma (A* in Table 1) is a good approximation to a parental magma for the SNC meteorites; parental melt estimates for other SNC's are similar low-Al, high-FeO basalts. Experiments on the A* basaltic composition melt showed that with no water in the system, the residual melt did not reach the Pathfinder sulfur-free rock (andesite) composition until there was only a few (< 5) percent residual melt present in the experimental sample. However, hydrothermal experiments showed that with as little as 1 wt % of dissolved water, the melt remaining after about 60 % crystallization of the A* composition was very similar in all respects to the “sulfur-free” andesitic composition rock discovered at the Pathfinder site (PA-1 in Fig.1). Furthermore, it was concluded that this melt would be relatively easy to separate from the coexisting crystals (phenocrysts) because of the low viscosity of the melt composition (low-Al, high-Fe, and H_2O -enriched). Experiments also confirmed that higher oxidation states in the water-bearing magma (higher than the QFM buffer) would enhance the effects of the water, by causing even more crystallization of Fe-oxides in place of Fe-Mg silicates such as pyroxene. Recently, Foley et al. (2001) revised the composition of the Pathfinder andesite based on a recalibration of the APXS instrument, lowering the SiO_2 (62 to 57.7 wt %) and raising the FeO (12.0 to 16.6 wt %). Although the solution is not as good, this composition is also produced from the SNC basaltic melt starting material provided there is at least 1 wt % dissolved water in the melt (Fig.1).

It has been suggested (Bruckner et al., 1999) that the Mars Pathfinder and Viking soil compositions can be approximated as a mixture of SNC meteorite material and the Pathfinder andesite in approximately equal proportions. We (Rutherford et al., 1999) have refined this calculation theorizing that SNC magmas erupted on the Mars surface are likely to be mixtures of melt and some early formed crystals of olivine and/or pyroxene. Mixing calculations done using the well constrained SNC basaltic melt composition as one end member, Fo₇₄ olivine (as found on the liquidus of many SNC melts), and the Pathfinder andesite composition, show that the Mars soils are nicely explained as a 50:10:40 mixture of these end-members. We are continuing to work on this problem.

Task (2) Spectral effects of oxidation on basalt spectra. This task was an investigation of the possible effects of oxidation on the VISNIR and mid-infrared spectral properties of a pyroxene- and plagioclase-bearing basalt. We chose to work on the SNC parent melt composition, A*. The goal was to determine whether oxidation effects which produced an obvious reddening of the spectra, could affect the pyroxene/plagioclase ratio estimated from the mid-IR spectra (Minitti et al., 2000; 2001b).

SNC basalt samples of varying crystallinities were synthesized and subsequently oxidized in air at 700 °C for 1,3, and 7 days. Reflectance spectra of both fine (<75 µm) and coarse (75-500µm) basalt samples were obtained before and after each oxidation. The unoxidized products revealed that crystallization produces progressive changes in VISNIR and mid-IR spectra. In the VISNIR, changes with increasing crystallization are due to the increasing influence of pyroxene absorptions while in the mid-IR, changes are due to variations in the amount of glass, pyroxene and plagioclase. Oxidation alters the glass and pyroxenes within the samples, leading to changes in VISNIR and mid-IR spectral shapes, although distinct signatures of oxidation products were not always observed. Both spectral and electron microscopy data indicate that hematite is the dominant oxidation product in the pigeonite and glass samples. In pigeonite, hematite is present in nanophase form and leads to a decrease in the diagnostic 1- and 2- µm pyroxene absorptions in the VISNIR as well as the pyroxene absorptions between 800 and 1100 cm⁻¹ in the mid-IR. In glass, hematite forms a near-surface layer that is detected with varying efficiencies in the VISNIR and the mid-IR depending on the crystallinity and particle size of the analyzed sample. We found that oxidized SNC basalt samples of various crystallinities and fine grain sizes provide the best analogs to Mars remote sensing data in the VISNIR and mid-IR. In the VISNIR, partially crystalline, oxidized SNC basalts can reproduce Martian dark region characteristics. In the mid-IR, similarities exist between the spectra of a partially crystalline,

oxidized SNC basalt and the basalt lithology detected by TES. The andesite lithology detected by TES is best matched by the spectrum of a fully crystalline, oxidized, SNC basalt. These results imply that plagioclase-rich lithologies are not required by TES data and that observed variations in spectral character of dark regions across the Martian surface can be explained by SNC basalts influenced by oxidation coupled with variations in degree of crystallization. In retrospect, it may have been more revealing to study the effects of groundmass crystallization and oxidation separately since the above experiments produced the two simultaneously, and both appear to have spectral effects. In task 2 of the present proposal we describe work that will determine the effects separately.

Over the next few months we will complete the work on the two Pathfinder andesite compositions (Minitti et al., 2001) which we have synthesized, and the spectral studies of these samples. We have variably crystallized samples of these andesite compositions and have oxidized most of them experimentally. The last of the spectral studies is now in progress.

Publications:

1. Minitti, M.E., and Rutherford, M.J. (2000) Genesis of the Pathfinder "sulfur-free" rock from SNC parental liquids. *GCA*, 64, 2535-2547.
2. Minitti, M.E., and Rutherford, M.J., and Weitz, C.M., 2001, Spectra of Mars Andesitic Material. LPSC XXXII, 1976. pdf.
3. McCanta, M.C., and Rutherford, M.J. 2001, SNC oxygen fugacity as recorded in pyroxene: an experimental study. LPSC XXXIII, 1348.pdf.
4. Rutherford, M.J. et al., 2001, Composition of Mars Rocks: SNC meteorites, Differentiates, and soils. Workshop on Mars 2001. 92-93.
5. Minitti, M.E., Mustard, J.F., and Rutherford, M.J., (2002) The effects of Glass content and Oxidation on the spectra of SNC-like basalts: Applications to Mars Remote Sensing. *JGR*, 107, E5, 6-1 to 6-14.

Recent Abstracts of Talks presented at Scientific meetings:

- Minitti, M and Rutherford, M.J. (1999) Genesis of the Mars Pathfinder "sulfur-free" rock from SNC parental liquids. *Proc. 5th Mars Conference*
- Weitz, C.M., and Rutherford, M.J. (1999) Some petrological explanations for the Magnetic anomalies detected on Mars. *Proc 5th Mars Conf.*
- Rutherford, M.J., Minitti, M and Weitz, C.M., (1999) Compositions of Mars rocks, SNC meteorites, magmatic differentiates, and Mars soils. *Mars 2001 workshop, LPI*, 80-81.
- Minitti, M.E., Rutherford, M.J., and Mustard, J.F., (2000) The effects of Oxidation on the spectra of SNC-like basalts: Applications to Mars Remote Sensing. *LPSC XXXI*, #1282.
- Rutherford, M.J. and Weitz, C.M., (2000) Petrology and Mars Magnetic Anomalies. *Abstracts of Spring AGU meeting, May 2000, Washington D.C.*
- Minitti, M.E., Rutherford, M.J., and Weitz, C.M., 2001, Spectra of Martian Andesitic materials. *LPSC 32*, # 1976.
- McCanta, M.C., and Rutherford, M.J. (2001) SNC oxygen fugacity as recorded in Pyroxenes: an experimental study. *LPSC 32*, #1938.